CURRENT STATE OF PESTICIDE APPLICATION TECHNOLOGY IN THE U.S.A.

H. Erdal Ozkan
Professor Agri. Engineering Dept.
The Ohio Sate University Columbus, Ohio U.S.A.

ABSTRACT

Although application methods and equipment have improved, chemical application is still an inefficient operation. Often only a small portion of the spray chemical actually reaches the target and contributes to the desired biological effect. There have not been many major changes in the design of application equipment for several years. Some of the recent pesticide application research programs and technological developments in the U.S.A. are discussed in this paper.

INTRODUCTION

The use of synthetic organic pesticides in the U.S.A began in the 1940's. Total amount of farm pesticide use has tripled between 1950 and 1985. The total amount of pesticide active ingredients applied on farms increased 174 percent between 1964 and 1982 while total area under cultivation remained nearly constant. Herbicide use was predominant and increased from 95 million kg of active ingredient in 1971 to a peak of 206 million kg in 1982 (USDA, 1984). In 1985, approximately 95% of the corn and soybean fields was treated with herbicides, compared to about 40 percent in 1970. As a percent of total pesticide amount applied, herbicides rose from 33% in 1966 to 90% in 1986 (USDA, 1970; 1986). During that time insecticide use declined while fungicide use stayed relatively the same. Total pesticide use has declined from more than 227 million kg of active ingredient in 1982 to about 195 million kg in 1987. The greatest volume of pesticides is applied on field crops. About 90 percent of all herbicides and insecticides are applied on four crops; corn, cotton, soybeans and wheat (USDA, 1986). In 1986, corn alone accounted for 55% of all herbicides and 44% of all insecticides used on field crops. Nearly half the total amount of pesticides was used in corn production. Soybeans received about 25% of all herbicides, and cotton about 25% of all insecticides. Fungicides now account for less than 10% of all pesticides applied in agriculture.

The success of pesticide applications depends on the accuracy of placement on the target. Most herbicides used on row crops are applied by sprayers powered by tractors. About two-thirds of all insecticides and fungicides are applied aerially. Citrus orchards may be aerially treated 10 to 20 times per season with insecticides, fungicides and protectant oils. Helicopters are often used because the turbulence from the main rotor tends to push the pesticides down toward the crop. Fixed-wing aircraft are more commonly used in field crops such as wheat and cotton. Although the current chemi-

application methods and equipment have improved the application accuracy considerably, chemical application is still an inefficient application. Often only a small portion of the spray chemical actually reaches the target and contributes to the desired biological effect.

RESEARCH THRUST AREAS

The main focus of the chemical application research in the U.S.A. has been to develop and adopt application techniques to increase the percentage of the chemical deposited on the target, and to protect the environment from contamination by pesticides. Some of the major research areas in pesticide application technology in the last decade include in-line injection of pesticides, spray drift, shielded booms, the management and disposal of pesticide wastes, subsurface placement of pesticides, techniques for measuring spray deposits on targets, spray droplet size analysis, retention of droplets on target surfaces, and new atomizers such as controlled droplet applicators and electrostatic nozzles. Following is a summary of research and educational activities that we are involved in Ohio, and brief discussion of some other studies conducted elsewhere in the U.S.A.

Ohio Studies

In-line Pesticide Injection Systems

Safe disposal of unused tank mixtures after spraying is a major problem. Due to many variables, it is almost impossible to make a quantity of pesticide and water that will be exactly enough for the intended treatment. Sprayer operators tend to make a larger tank mixture than needed to insure that there will be plenty of mixture for the treatment. It is common to have unused mixtures of pesticide and water after the pesticide application. Safe disposal of unused tank mixtures creates problems. Some have suggested that the operator dilute the unused mixture and spray it over the treated area. However, such practice could result in excessive pesticide residue on the treated crop. Improper disposal of the unused mixture may contaminate the water supply due to runoff after rainfall and leaching.

It is possible to eliminate unused tank mixtures after spraying if sprayers with in-line pesticide injection systems are used. When in-line pesticide injection systems are used, the only left-over liquids are the water in the water tank and the pest icide in the pesticide tank. The unused pesticide can be kept in the pesticide tank for the next application or drained through a tube into the original pesticide container. Reichard and Ladd (1983) developed and tested a field sprayer that would meter pesticides at the proper rate, regardless of travel speed, and mix the pesticides with water in line to nozzles. The sprayer also included a portable closed system of pesticides from shipping containers to the pesticide tank on the sprayer.

Although it is obvious that the in-line direct injection of pesticides is an effective method of reducing operator exposure and left over chemical mixtures, injection systems have not been widely accepted by applicators. The reasons are: (a) slow response time of the systems after sudden changes

in travel speeds, (b) inadequate mixing of some chemicals in the spray line which results in non uniform application, and (c) higher cost and maintenance requirements. To reduce the time lag problem, some researchers have studied direct injection of pesticides into the nozzle body. Although some progress was made in reducing the response time, the complexity and non uniform mixing of chemicals with the carrier remain as the major problems associated with this system. Research in this area will continue to eliminate or reduce these problems.

Uniform mixing of pesticides in sprayer tanks

Achieving satisfactory results with a sprayer is greatly dependent on the performance of many sprayer components. One component often overlooked is the agitation mechanism. When some pesticides, especially wettable powders, are added to tanks with insufficient agitation, they either tend to float on the surface of the liquid or settle to the bottom of the tank. In either case, the result will be non uniform distribution of pesticides on the target. While some treated areas may not receive enough pesticides, other areas will receive too much. Not enough pesticide causes ineffective pest control, while an overdose increases the cost of production, and may damage the crop.

Unfortunately there has been little investigation of the uniformity of pesticide distribution in sprayer tanks during spray applications. The latest known research was conducted almost three decades ago. The predominant tanks on tractor mounted sprayers then were standard, uniformly shaped 206-liter (55 gallon) oil drums. Sprayer tanks today can hold as much as 4000 liters, and they have a wide range of shapes. In spite of these changes in size and shape, the agitation methods and mechanisms in sprayer tanks have remained basically the same and little is known about what is required to provide uniform mixtures.

A thorough investigation of current agitation systems should lead to the development of better tank mixing systems. Improvements in the mixing technology could: a) result in more efficient use of pesticides, application equipment, and applicator time; b) avoid under application of pesticides which could cause reduced yields and increased production costs because of additional applications that may be necessary; c) eliminate over application which could lead to crop damage, increased production costs and costly litigation's between the farmer and others.

Research is underway to determine variation in the pesticide concentration at several points in the tank during the entire spray application for various agitation systems. Two methods are being developed to determine uniformity of pesticide concentration at various locations in spray tanks. The first method is based on the amount of light transmitted across a gap between two fiber optic probes. A high amount of light transmission indicates low pesticide concentration. The second method consists of drawing small liquid samples simultaneously from different locations in the tank, drying and weighing the residues. The results of this research should determine an effective and agitation system for pesticides difficult to mix with water for various tank sizes.

Retention of spray droplets on targets

The performance of chemicals is directly related to the retention of droplets on the target. Until

recently, research on the impaction and retention of droplets on spray targets has been neglected because of the many variables involved and lack of suitable equipment for the research. We are studying rebound of droplets on the target surface by using high speed photographic techniques which enable us to see actions that could not normally be seen. A high speed 16 mm motion picture camera is used to take 6000 pictures per second. Viewing the film at 24 pictures per second provides time magnification of 250.

Our initial studies show that for some operating conditions a large portion of the spray droplets rebound from the spray target. Among 35 different plant leaves used as a target, 12 were very reflective of spray droplets. The micro structure of the leaf surface greatly influences whether a droplet rebounds or not. Of the variables we have studied so far, adding surfactant to the water is the best way to reduce the rebound of spray droplets from leaves that tend to reflect drops. The optimum type and amount of surfactant is yet to determined. Research will continue to improve the deposition efficiency of spray droplets through a better understanding of the impaction process.

Application accuracy

The effects of pesticides on the targets are greatly influenced by the method and timing of application and the operation and accuracy of the equipment used. Labels on pesticide containers indicate the proper application rates. However, these rates can be achieved only if sprayers are calibrated. Growing concerns about pesticide contamination of ground water and increasing chemical costs makes accurate application of pesticides even more important than in the past.

We have been conducting traditional extension meetings in counties to each farmers how to calibrate sprayers. Unfortunately most of these classroom oriented programs have not been very effective. A more successful approach has been the calibration clinics which invites audience participation and hands-on practices. At these clinics, the operators were asked what their intended application rates were before sprayers were calibrated. This was compared with the actual rate of application. Regulatory guidelines in the U.S. indicate that the application error should be within 5% of the recommended or desired rate. Of the 80 sprayers tested, only 20% were capable of applying a tank mix within $\pm$ 5% of the intended application rate. Of those 64 sprayers showing an unacceptable performance, roughly one-half overapplied the spray mix while the other one-half underapplied. A unique part of these sprayer calibration clinics was the use of a microcomputer program SPRAYCAL (Ozkan, 1987), developed mainly to emphasize the economic aspects of using improperly calibrated sprayers. For an overapplication, SPRAYCAL determines the amount of pesticide wasted and the subsequent cost to the farmer.

Wear life of agricultural spray nozzles

Calibration clinics conducted in Ohio revealed that more than 1/3 of the sprayers surveyed were overapplying chemicals. The major reason for overapplication was nozzles. No general recommendations exist for how often nozzles should be replaced. Nozzle tips are made from a variety of materials including stainless steel, brass, nylon, plastic and ceramic. All of these materials

have different wear characteristics.

We are investigating the effect of nozzle wear on both flow rate and spray pattern. To study the change in flow rate, a mixture of water and an abrasive wear agent (kaolin) is continuously circulated through nozzles. As many as 18 nozzles can be tested simultaneously. In addition to the type of nozzle material, the system will be used to study other factors that affect wear rate such as orifice size and shape, material used in tank mix and operating pressure. After circulating a 150 liter tank mixture that contains 60 grams of Hydrite Flat D (Georgia Kaolin Co.) per liter of water through 3 each of brass, nylon, and stainless steel nozzles delivering 0.75 liter/minute for 40 hours, the increase in flow rate with these nozzles were 28.9%, 11.7 and 10.4% respectively. Although not included in our current wear tests, data from various university and industry research stations indicate that nozzles made from ceramic are most resistant to wear.

Nozzle wear also changes the spray pattern of nozzles. Distortions in the nozzle pattern could lead to non-uniform spray distributions causing streaks with poor pest control and/or an excessive amount of chemicals. We have constructed an automated spray patternator table to investigate the changes in spray pattern of nozzles as a result of wear.

Subsurface placement of agricultural chemicals

Surface applications often result in inefficient use of agricultural chemicals. When agricultural chemicals are broadcast, they are subject to different types and amounts of losses. In addition, surface applications of pesticides can be hazardous to people, and animals exposed to the pesticides. This risk is often greater in areas such as home lawns, parks, and golf courses where there is considerable chance for human contact with the pesticides applied on the grass surfaces. To reduce this danger, injection systems were developed to place pesticides below soil surface. Current results indicate that fertilizers and pesticides can be successfully injected with little damage to the surface.

Spray drift evaluation

The problem of spray drift, movement of a pesticide to a site other than the intended site of application, remains a serious problem. Reduced spray drift not only reduces environmental pollution but also improves application efficiency. There have been many research projects conducted to study spray drift. Unfortunately, there are still many unknowns regarding spray drift.

Weather conditions, which the applicator has no control over, play an important role in the creation as well as reduction of drift. Two other factors which influence spray drift are chemical formulations, and application parameters which include selection and proper operation of the spray equipment. The most important application factor influencing drift is the size of droplets produced by spray atomizers. Research has shown that droplets smaller than 150 μm in diameter have a tendency to drift during many typical spray application conditions. For typical applications with boom type sprayers, droplets of 100 μm or less drift out of the intended swath and 50 μm or less diameter droplets, completely evaporate before reaching the target (Bode, 1984). Although the number of small droplets produced by conventional nozzles used with ground sprayers are high, the total volume of

spray made up of droplets less than 100 μm in diameter is relatively small. But, the spray drift should be reduced as much as practical.

Small spray droplets are desirable, especially for insect control in orchards, because they provide better penetration into the canopy and a better coverage. Air blast sprayers which produce a relatively high number of small droplets and also direct the spray upward are commonly used to apply fungicides and insecticides in orchards. Spray drift can be a more serious problem with air blast spraying. Most spray drift research, however, has centered on aircraft or ground operated boom sprayer applications. Few studies of drift from orchard air sprayers have been reported. The first step in developing some strategies to reduce spray drift is to measure the amount of drift occurring under different application parameters. Actual pesticides as well as tracers such as salts, color, and fluorescent dyes have been used by researchers for measuring spray deposits collected on foliage, cards, plastic sheets, paper tape, string, bottles, and other targets.

Fox et al. (1990) conducted a study to measure the deposition pattern of spray material produced by orchard sprayer and to compare several types of spray collectors. They measured ground deposits using 10 × 20 cm plastic sheets. The airborne spray deposits from the sprayer were measured using bottles as well as strings mounted on vertical collection racks 3.0, 4.5 and 15 m away from the sprayer. The mixture, containing tracer, was applied at a rate of 470 L/ha using an air blast orchard sprayer equipped with 6, disk-core type, hollow cone nozzles. Sprayer operating pressure was 900 kPa. The results of this study indicate that most of the spray was collected at 1 m elevation and that deposits steadily decreased as height increased. About 3.5% of the released spray was still air borne at 122 m from the spray line. Spray deposited on the ground between 150 and 300 m was less than 0.1% of the material released.

Field research at several universities have indicated that adding certain adjuvants in the spray solution can reduce the number of drift-prone droplets. In addition, some of these thickening agents reduce the evaporation rate of droplets as much as 30% (Bode, 1981). Reduced pressure at the nozzle also generally causes an increase in the volume median droplet size. The pressure range recommended for conventional hydraulic flat fan nozzles is from about 200 kPa to 350 kPa. Recently, nozzle manufacturers in the U.S. have introduced new nozzles that can be used at pressures as low as 100 kPa. Test results have verified that drift deposits from these nozzles are much lower than those from popular nozzles. Additional research is needed to determine the most efficient application equipment and methods to reduce drift.

Droplet size characterization and its effect on pest control

Studies conducted recently indicate that spray coverage in terms of number of droplets per unit area is an important factor in achieving maximum phytotoxic effect from a pesticide. All commercially available spray atomizers produce a range of droplet sizes, some ranging from under 10 μm to over 1000 μ m. The droplet size range, however, can be altered by changing the viscosity of the pesticide formulation through the addition of some adjuvants to the mixture. Research is underway to determine the effects of pesticide formulations and concentrations; oils; atomizer types, sizes and

orientations on size distributions of spray droplets produced by agricultural nozzles.

The requirements for coverage, provided by different sizes of droplets and application rates varies with pesticides. Therefore, in order to improve the efficiency and effectiveness of spray applications for pest control and other uses, information is needed on the effects of various drop sizes and number of drops per unit area. Currently several types of laser equipment are available to determine the droplet sizes generated by nozzles. It is, however, necessary to isolate a given size of droplet from others in order to study the effect of droplet size on biological efficiency achieved from different pesticides. Various devices have been used to produce narrow ranges, or uniform sizes of drops in the past. None have been widely accepted by researchers for different reasons, but usually because these units could not easily produce a wide range of uniform-size drops or vary the number of drops per unit area. Reichard et al (1987) developed a drop generator and associated system to study the effect of drop size and number of drops/unit area on insect control. Another experimental drop generator permits production of uniform-size drops within a range of about 100 to 1800 μm diameter. The operator can select the number of drops delivered from 1 to 10000 and the frequency of drop production from a single drop when desired to over 10 drops/second.

Electrostatic Spraying of Pesticides

Gravity and wind are the two major forces affecting deposition of spray droplets produced by conventional nozzles. Small droplets, especially those with a diameter of less than 100 um, reach terminal velocity soon after they are released from a nozzle, and are subject to being swept away from the application site by movement of air currents. This results in increased drift and reduced coverage especially on the undersides of plant leaves. Electrostatic charging of small droplets has been considered as a possible way to increase the deposition efficiency of small droplets.

Although research on electrostatic spraying in industrial applications has been conducted for more than 50 years, the use of charged sprays was not extended to agriculture until early 1970's. Law (1978) designed an experimental electrostatic atomizer and reported excellent insect control when only one-half of the recommended rate of insecticide was applied. Several electrostatic atomizers have been designed and marketed especially in Europe. However, these atomizers have not gained wide acceptance by farmers. Currently there are no mass produced electrostatic atomizers in the U.S. Increased public concern about the environment and the push towards reduced pesticide consumption are likely to provide the impetus to stimulate further investigation of electrostatic spray systems. Some universities in the U.S. have research programs in this area. Most of these programs have been directed towards complementing low volume application systems with the use of electrostatic charging.

Review of Other Technical Developments

The utilization of electronic sensors, monitors and computer automated controllers in agricultural machines has increased significantly in the last decade. Pesticide application equipment has had many electronic adaptations. The measurement of travel speed, operating pressure, fluid flow rate,

area covered, amount of liquid left in the spray tank can now be performed with electronic sensors. Many monitors and controllers are available commercially in the U.S. Most of these systems use a radar sensor to determine the travel speed. Fluid pressure is electronically measured with a pressure transducer, and the fluid flow is measured either with a "paddle wheel" or turbine flow meter. Ayers and Ragowski (1989) have recently evaluated one of the most popular monitors in the U.S. and found satisfactory performance.

Several computer vision and image processing systems are being developed to detect the weed. They are followed by the application of herbicide directly to the weed. Cheshire et al. (1988) developed a technique for detecting the locations of two soil insecticides after their incorporation into soil. The technique involved treatment of the insecticide granules with iodine and a thin coating of lead dust. The granules were detected in soil samples with X-ray computed tomography (CAT scanning). Statistical analysis indicated significant differences between incorporation procedures for dispersion of granules, location of granules, and number of granules detected. Harrowing or rototilling immediately after broadcast insecticide treatments resulted in the shallowest and most variation in distribution of granules.

Recently there is interest in the use of field crop sprayers with some form of wind protection for the nozzles in order to reduce wind drift and improve application efficiency. A Canadian manufacturing firm has designed different types of protective sprayer attachment including complete shrouds over the entire boom, wind shields in front of or behind the nozzles, or small hoods over each nozzle (Rogers and Jackson, 1987). Each of these forms of protection, particularly the complete shroud, restricts the operator's ability to visually monitor the nozzles for plugging. Robertson et al. (1988) has developed a detector which measures the airborne sound of the spray and gives warning to the operator if any significant change occur in the initial sound level.

The current methods of handling pesticides poses substantial health risks to applicators. Findings of a study indicate that most of the contamination takes place while transporting, pouring and mixing chemicals. Wesley et al. (1988) designed an enclosed system for mixing and loading both dry and liquid pesticide concentrates without exposing the operator to hazardous materials.

Public concern in the U.S. over disposal of leftover pesticides and pesticide containers is growing continuously. Although in-line injection systems may eliminate the amount of leftover pesticide mixtures in the tank, the problem of container disposal still remains as a potential health hazard. In 1986, about 223 million empty pesticide containers were generated in the U.S., 80 million of them from agriculture (Kepple, 1989). Realizing this problem, pesticide manufacturers have been promoting the use of refillable or recyclable pesticide containers. Most of the major chemical companies now have at least one of such units on the market. These units are usually referred to as mini-bulk or turn-around tank systems. One problem with some of these bulk containers is inadequate metering and not knowing the exact amount of chemical left in the container. Research is being done to investigate the feasibility of adding inexpensive control and monitoring equipment to mini-bulk containers (Howard et al., 1989).

Several are doing research in the U.S. on the fate of agricultural chemicals after their application. The potential movement of pesticides from application site to lakes, streams and ground water resources is a concern of the public, researchers and chemical companies. Management strategies are being developed to provide effective control of surface pesticide transport by reducing the sediment and runoff in which pesticides are carried. One of the most effective ways to reduce the surface water run off is with a crop residue cover on the soil surface. Although some conservation tillage practices require additional herbicide for effective weed control, a common conclusion reached by many scientists is that pesticide losses from fields under conservation tillage systems are generally much less than losses from fields under conventional moldboard plow tillage systems. A recent study by Kenimer et al. (1989) showed this. In addition, they indicated that contour tillage generally yielded lower pesticide losses than up and-down tillage.

CONCLUSIONS

Although current chemical application methods and equipment have improved application accuracy considerably, chemical application is still an inefficient operation. Often only a small portion of the spray chemical actually reaches the target and contributes to the biological effect. Recent concerns over the contamination of water resources with pesticides has provided a new impetus for scientists to develop methods and equipment to increase the efficiency of pesticide application improvements in pesticide application efficiency will result in less pesticide consumption, less pollution of the environment and reduced energy requirements in the manufacture of pesticides.

REFERENCES

Ayers, P.D. and S.M. Rogowski. 1989. Evaluation of sprayer control system performance. ASAE Paper No. 89-1003. ASAE, St. Joseph, MI 49085.

Bode, L.E. 1981. New pesticide application equipment and techniques. Plant Disease 65(1):32-36.

Bode, LE. 1984. Downwind drift deposits by ground applications. Proceedings of the Pesticide Drift Management Symposium. South Dakota State University, Brookings, SD, pp 49-52.

Cheshire, J.M., E.W. Tollner, B.P. Verma and W.M. Blum. 1988. Radiographic detection of soil-incorporated granular pesticides and impacts of application methods on wire worm management. ASAE Paper No. 88-1013, St. Joseph, MI 49085.

Fox, R.D., R.D. Brazee, D.L. Reichard and F.R. Hall. 1990. Drift from an orchard air sprayer. Submitted to Transactions of the ASAE for publication.

Howard, K.D., S.C. Young and D.K. Kuhlman. 1989. Concept for improving the handling and metering of agricultural chemicals. ASAE Paper No. 89-1612. ASAE, St. Joseph, MI 49085.

Kenimer, A.L. J.K. Mitchell and A.S. Felsot. 1989. Pesticide losses as affected by tillage system and row direction. ASAE Paper No. 89-2118. ASAE, St. Joseph, MI 49085.

Kepple, D.D. 1989. What to do about waste. Agrichemical Age 33(2):18-19.

Law, S.E. 1978. Embedded electrode electrostatic induction spray charging nozzle: theoretical and

engineering design. Transactions of the ASAE 21(6):1096-1104.

Ozkan, H.E. 1987. Sprayer performance evaluation with microcomputers. Applied Engineering in Agriculture 3(1):36-41.

Reichard, D.L. and T.L. Ladd. 1983. Pesticide injection and transfer system for field sprayers. Transactions of the ASAE 26(3):683-686.

Reichard, D.L., S.R. Alm and F.R. Hall. 1987. Equipment for studying the effects of spray drop size, distribution, and dosage in pest control. Journal of Economic Entomology 80(2):540-543.

Robertson, K.A., J. Baker and F. Sawyer. 1988. Nozzle monitoring systems for field crop sprayers. ASAE Paper No. 88-1582. ASAE, St. Joseph, MI 49085.

Rogers, R.B. and K. Jackson. 1987. Autotrans windfoil sprayer. ASAE Paper No. 87-1639, ASAE, St. Joseph, MI 49085.

USDA. 1970. Quantities of pesticide used by farmers in 1966. Agricultural Economic Report No. 179. Economic Research Service, Washington, D.C.

USDA. 1984. Inputs-outlook and situation report. IOS-6. Economic Research Service, Washington, D. C.

USDA. 1986. Agricultural resources-inputs outlook and situation report. AR-1 Economic Research Service, Washington, D. C.

Wesley, R.A., L.A. Smith and J.R. Williford. 1988. An enclosed system for pesticide mixing and loading. ASAE Paper No. 88-1583. ASAE, St. Joseph, MI 49085.